## REMARKS

FIGS. 3A and 3B were added to the parent patent application (U.S. Patent Application Serial No. 09/835,794, filed April 1, 2001, now U.S. Patent No. 6,652,194) in satisfaction of an objection of the Examiner and the amendments to the specification submitted herewith were also made in the specification of the parent patent application U.S. Patent Application Serial No. 09/835,794, now U.S. Patent No. 6,652,194. The application was filed with the originally filed specification, which did not include the amendments submitted herewith and amendment of the specification as made herein was unfortunately overlooked prior to now.

Applicant respectfully requests that the amendments to the specification submitted herewith be entered.

For the convenience of the Office, a re-typed patent specification, pages 6 to 18a are attached hereto.

Respectfully submitted,

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the toothed racks; retracting their pistons substantially entirely within the cylinders of the piston/cylinder units and re-engaging the retracted toothed rack engagement members of said portion of the piston/cylinder units while maintaining engagement of the remainder of the toothed rack engagement members with the toothed racks; and repeating the operation with different portions of the toothed rack engagement members of the plurality of piston/cylinder units until all pistons of the plurality of piston/cylinder units are substantially entirely within their cylinders with all toothed rack engagement members engaged with the toothed racks.

A method of manufacturing a MODU jacking system capable of withstanding at least a maximum leg load of W, comprising: manufacturing a plurality of MODU supporting legs capable of carrying a plurality of toothed racks; selecting a number of toothed racks R and fastening the toothed racks on the plurality of MODU supporting legs; and selecting a number of hydraulic piston/cylinders N, having commercially available diameters d; manufacturing a plurality of rack engagement members capable of engagement with the toothed racks and attaching a rack engagement member to each piston of each hydraulic piston/cylinder; providing a source of hydraulic pressure P on the MODU to provide relative motion between the MODU and the MODU supporting legs by application of hydraulic pressure to the hydraulic piston/cylinders; and fastening said plurality of hydraulic piston/cylinder units to the MODU in a manner permitting engagement of their rack engagement members with the toothed racks, said selection of the number R of toothed racks, the number N of hydraulic piston/cylinders per rack, and the diameter d of the pistons being defined by

$$\frac{\pi P\, Rd^2(N-1)}{4} \geq W$$

Further inventive features and combinations are presented in the drawings and more detailed descriptions of the invention that follow.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic illustration of a jack-up MODU in position offshore;

FIG. 2 is a view from above the MODU of FIG. 1, for example, at line 2-2 of FIG. 1, to illustrate the relationship between the MODU platform and its MODU supporting legs;

FIG. 3 illustrates a continuous linear motion motor (and its MODU supporting structure) and the engagement of its plurality of piston/cylinder units with a toothed rack and leg chord, with the piston/cylinder units in their locked position;

FIG. 3A illustrates one of the piston/cylinder units of FIG. 3 with its rack engagement member engaged with the toothed rack through the action of a compression spring, and also

illustrates a motion sensor for sensing the relative rate of movement of a MODU supporting leg; and FIG. 3B is a partial cross-sectional view of FIG. 3A taken at a plane 3B-3B through the central axis of a pivot pin of a piston/cylinder unit to illustrate a load sensor included in the pivotal attachment of the piston/cylinder unit of FIG. 3A.

FIG. 4 is a view taken from above FIG. 3;

FIGS. 5-9 illustrate the phased operation of two sets of three hydraulically driven piston cylinder units to effect continuous linear motion, FIG. 9 comprising a phase diagram for the operations of the pistons as illustrated by FIGS. 5-8;

FIG. 10 is a phase diagram of seven piston/cylinder units operating to provide continuous linear motion;

FIG. 11 is a cross-sectional illustration of a preferred tooth profile of the invention;

FIGS. 12-15 diagrammatically illustrate how the pivotal attachment of a driving piston/cylinder unit to the MODU combines with the preferred tooth profile of FIG. 11 to provide an application of driving force uniformly and normally on the teeth with the piston at mid-stroke (FIG. 14), and to generate forces resisting the disengagement of the teeth when the pistons are retracted and the MODU is in its locking mode (FIG. 13), and to generate forces assisting the disengagement of the teeth when the pistons are at the end of their stroke (FIG. 15); and

FIG. 16 is an illustration of a screen providing a user interface with a jacking system control in this invention.

## DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 illustrates a jack-up MODU 20 at an offshore drilling site. MODU 20 comprises a platform structure 21, and a plurality of MODU supporting legs 22. Jack-up MODU 20 also includes a jacking system, as described herein, to provide relative motion between the MODU platform 21 and the plurality of supporting legs 22. As illustrated in FIG. 1, MODU platform 21 is supported by the MODU legs 22 from the earth's surface (because of their length, the MODU supporting legs 22 are shown only in part in FIG. 1) substantially above the water level 25.

As constructed and transported, the MODU platform 21 is in a position closely adjacent leg footings 23. The MODU platform 21 is buoyant so the MODU 20 comprises a vessel which can be towed to an exploration site. At the exploration site, the supporting legs 22 are lowered by the jacking system with respect to the platform 21 until the footings 23 reach the earth's surface 24, and the platform 21 is thereafter lifted by the jacking system to a position above the water surface 25.

The invention comprises a novel jacking system to provide relative motion between the MODU platform 21 and its plurality of supporting legs 22, and to lift and lower the massive MODU platform, including all of the supplies, personnel and equipment that it carries, with respect to the earth's surface 24, and to lock the MODU platform 21 in a stationary selected position without the use of any separate locking apparatus. As a result of the inventive features and combinations described herein, the weight of the MODU jacking system components is reduced, the material comprising the leg chords of the supporting legs is reduced, the need for expensive high-strength steels in the jack-up system is eliminated, the capacity of the jacking system for lifting is increased, the need for gear lubrication is eliminated, the cost of the jack-up system and its manufacture is reduced, the loads on each of the supporting legs is readily monitored, and the engineering of the jacking system is substantially simplified.

FIG. 2 is a view from above one of the MODU supporting legs 22 to illustrate how the supporting legs 22 and the MODU platform 21 are movably engaged. As illustrated by FIGS. 1 and 2, each of the plurality of supporting legs 22 can be comprised of three leg chords 26 at the three corners of a triangular-shaped leg support 22. The three leg chords 26 are welded into a supporting leg structure 22 which may be of any configuration that provides sufficient strength to carry the weight of the MODU platform 21 and its top side loads, which may be as much as 20,000 to 30,000 tons. Each of the three supporting legs 22 extend through an opening 21a in the decks comprising the MODU platform 21, the upper deck 21b being illustrated in FIG. 2.

The leg chords 26 resulting from and making up part of this invention are additionally illustrated on a larger scale in FIGS. 3 and 4.

As best illustrated in FIG. 4, each of the leg chords 26 preferably comprises a cylindrical tubular column 27 with toothed racks 32 welded on opposite sides and positioned for engagement by continuous linear motion motors 30 which operate in the invention to provide continuous relative motion between the MODU platform 21 and the supporting legs 22 and to lock the MODU platform 21 into stationary position with respect to the MODU supporting legs 22. The peripheral outer surface of the cylindrical tubular member 27 of each leg chord 26 of each MODU supporting leg 22 is slidably engaged with bronze bushings (not shown) carried by the MODU platform 21 adjacent its upper deck 21b and lower deck 21c, and as needed therebetween, to prevent lateral relative motion between the MODU platform 21 and the plurality of supporting legs 22. As a result of the invention, the need for single toothed racks to extend completely through the leg chords of the supporting legs in order to resist the compressive forces imposed by the spur gear drives of the prior art has been

eliminated, along with the need to use the expensive, high tensile strength steel, (e.g., 100 KSI), in the leg chords, reducing the weight and cost of each supporting leg. For example, the weight reduction for three supporting legs having lengths of 670 to 680 feet can be as much as 1110 tons, and the cost reduction for three such supporting legs as much as $4,880,000, assuming a cost of $2.20 per constructed pound. Notwithstanding the reduced material of the leg chords 26, as a result of this invention, the leg chords 26 can have an equal or greater section modulus than the prior art systems.

As indicated above, the invention includes a plurality of continuous linear motion motors engaged with the plurality of MODU supporting legs to provide relative motion between the MODU platform 21 and its supporting legs 22. The term "continuous linear motion motor" as used herein refers to a plurality of hydraulic piston/cylinder units N whose piston operations are phased so that N-1 of the plurality of piston/cylinder units are engaged with a MODU-supporting leg 22 and providing relative motion while one of the piston/cylinder units is disengaged from the MODU-supporting leg 22 and is being repositioned for re-engagement with the supporting leg 22 to continue the relative motion. Continuous linear motion motors can comprise any number of piston/cylinder units necessary to provide relative motion between the MODU platform 21 (and its loads) and its supporting legs 22 in acting on one or more toothed racks; however, it is believed to be preferable that the plurality of hydraulic piston/cylinder units in the continuous linear motion motor comprise an even number of units divided into two sets of piston/cylinder units acting on two toothed racks 32 on opposite sides of a leg chord 30, as shown in FIGS. 3-8, to minimize the imposition of transverse shear stresses in the leg chord 26 and toothed racks 32. Toothed racks as used herein means one member or a plurality of members, forming a plurality of tooth engagement surfaces which are capable of accepting the imposition of driving forces sufficient to provide relative motion between a MODU platform 21 and a MODU supporting leg 32. Preferably, toothed racks comprise a plurality of teeth uniformly formed along one side, particularly with a plurality of teeth having angled planar engagement surfaces capable of spreading the stresses due to the driving force necessary for relative motion uniformly throughout the teeth, as described in greater detail below.

Because the number of hydraulic piston/cylinder units that may comprise a continuous linear motion motor is not limited in this invention, it is unnecessary to use expensive specially designed or sized hydraulic piston/cylinder units or hydraulic pumps, and the hydraulic piston/cylinder units and hydraulic pumps may be selected from the inexpensive, commercially available "standard" hydraulic piston/cylinder units and pumps. Continuous linear motion motor jack-up systems of this invention can be made for as much

as $2,500,000 less than comparable spur gear driven jack-up systems of comparable lifting capacity.

FIG. 3 illustrates, as an example, a continuous linear motion motor 30 comprising two sets 31 of three piston/cylinder units 33 each to provide continuous relative motion between the MODU platform 21 and the illustrated one of its supporting legs 22. Each of the piston/cylinder units 33 comprises a double-acting hydraulic cylinder, with a piston moving in response to hydraulic pressure applied at the ends of its cylinder to move outwardly from its cylinder and to retract inwardly within its cylinder. FIG. 3 illustrates the pistons of the piston/cylinder units 33 in their retracted position with their pistons substantially entirely enclosed within their cylinders. Each of the pistons of the plurality of piston/cylinder units 33 has a toothed rack engagement member 34 attached to its end and engaged, under the action of an engagement/disengagement means 35, with one of the toothed racks 32, thereby locking the MODU platform 21 in a stationary position with respect to its supporting legs 22. Because, in the invention, the continuous linear motion motors and their pluralities of piston/cylinder units can effectively lock the MODU platform in a stationary position with respect to its supporting legs, the need for the separate expensive platform leg locking apparatus used in the spur gear driven jacking systems is unnecessary, providing a substantial cost savings, for example, about $4,500,000 for a MODU with three MODU supporting legs. The structure of the supporting legs 22, except for the one illustrated leg chord 26 and toothed racks 32, have been omitted from FIG. 3 in order to better illustrate the plurality of cylinders 33 and the engagement of their toothed-rack engagement members 34.

The plurality of piston/cylinder units 33 comprising the continuous linear motion motors 30 that move the supporting leg 22 with respect to the MODU platform 21 are pivotally attached to and carried by structural towers 40 on the MODU platform 21 adjacent the leg chords 26 of the supporting legs. As indicated by the phantom lines in FIGS. 2 and 4, the MODU platform 21 includes structural members, as known in the art, to bear the load associated with the engagement of the MODU platform 21 and its plurality of supporting legs 22.

The continuous linear motion motor 30 includes a plurality of means 35 for engagement and disengagement of the toothed shoes 34 of the piston/cylinder units 33 with the toothed racks 32 by pivoting the piston/cylinder units 33 through a small angle. The engagement/disengagement means 35 for the rack engagement members 34 preferably comprise compression springs 36 that act on the rack engagement members 34 to urge them toward and into engagement with the toothed racks 32, as shown in FIG. 3A, and unclamp hydraulic piston/cylinder units 37 that act in response to the imposition of hydraulic pressure

within their cylinders to overcome the forces of the compression springs 36, moving the rack engagement members 34 away from and disengaged from the toothed racks 32. Such engagement/disengagement means 35 preferably comprise single-acting piston/cylinder units including the compression spring 36 within the cylinder acting on one side of the piston to push it outwardly from the cylinder in absence of pressure, with the application of pressure on the other side of the piston overcoming the force of the compression spring and moving the piston into the cylinder. With such preferred engagement/disengagement means, no power is required to engage and maintain the engagement of the toothed rack engagement members 34 with the toothed racks 32 in the locked mode; however, other controllable engagement/disengagement means, such as double acting hydraulic piston/cylinders, electric actuators and the like, may be used.

As described in greater detail below, the tooth profiles of the teeth of the toothed shoes 34 and of the teeth of the toothed racks 32 and the pivotal attachment of the cylinders 33 cooperate when the jacking system is in its locked mode with the pistons of piston/cylinder units 33 retracted into their cylinders to generate engagement forces assisting the engagement/disengagement means 35 in maintaining the toothed shoes 34 in engagement with the toothed racks 32 and maintaining the MODU platform 21 locked into a stationary position with respect to its supporting legs 22.

To simplify explanation of the operation of continuous liner motion motors two sets of three active hydraulic piston/cylinder units 33 are illustrated and described as comprising a continuous linear motion motor 30. It must be understood, however, that any plurality of piston/cylinder units N may comprise a continuous linear motion motor in the invention, provided their operation is sequentially phased, as, for example, illustrated in FIGS. 9 and 10, so that N-1 of the piston/cylinder units are engaged with a toothed rack and are providing relative motion between the MODU 21 platform and the MODU supporting legs 22 while one of the piston/cylinder units is being retracted and repositioned for reengagement with and driving of the supporting leg.

FIGS. 5-9 illustrate the phased operation of the three piston/cylinder units 33a, 33b and 33c of each set 31 to provide continuous linear motion acting on a leg chord 26 of one of the MODU supporting legs 22.

In providing continuous linear motion, the piston strokes of each of the piston/cylinder units 33a, 33b and 33c of each set 31, and the engagement and disengagement of their toothed rack engagement means 34 are phased, that is, their operations are displaced in time so that two of the piston/cylinder units have their rack engagement members 34 engaged with the toothed racks 32 of a leg chord 26 with their pistons being extended to drive

the leg chord 26 while the third piston/cylinder unit has its rack engagement member 34 disengaged from the toothed rack 32 of the leg chord 26 with its piston being retracted to reposition its rack engagement member 34 for reengagement with the toothed rack 32 and subsequent extension of its piston to drive the leg chord 26. This repetitive phased operation of the piston/cylinder units 33 to achieve linear motion is illustrated in the phase diagram FIG. 9.

At the point in time illustrated on FIG. 9 by the notation FIG. 5, the piston/cylinder units 33a, 33b and 33c have been driven so the pistons of piston/cylinder units 33a are fully extended, the piston/cylinder units 33b are in mid-stroke, and the piston/cylinder units 33c have just been engaged with toothed racks 32. At the point in time illustrated by FIG. 6 on the phase diagram of FIG. 9, the rack engagement members 34 of piston/cylinder units 33a have been disengaged from the toothed racks 32, while piston/cylinder units 33b and 33c continue to drive toothed racks 32 and leg chord 26 to the point illustrated in FIG. 7. At the point in time illustrated by FIG. 7, the pistons of piston/cylinder units 33a have been retracted and the rack engagement members 34 of piston/cylinder units 33a have been positioned for reengagement with the toothed racks 32, the piston/cylinder units 33b have been operated until their pistons are fully extended and the piston/cylinder units 33c have been operated until their pistons are in mid-stroke. Shortly after this time, as illustrated in FIG. 8, the rack engagement members 34 of piston/cylinder units 33a are reengaged with the toothed racks 32 as the pistons of piston/cylinder units 33b approach full extension and as the pistons of piston/cylinder units 33c are in mid-stroke. This phased operation of the toothed rack engagement members 34 by their engagement/disengagement means 35 and of the pistons of piston/cylinder units 33a, 33b and 33c continues in time, as indicated by FIG. 9, continuously driving (without interruption) the MODU supporting legs 22 with respect to the MODU platform 21.

As indicated above, it is not necessary that the continuous linear motion motors comprise sets of three piston/cylinder units, and in practical application, because of the substantial forces that are required to move the massive weights of a MODU platform and the loads that it carries, and MODU supporting legs with respect to each other, continuous linear motion motors incorporated into MODU jacking systems will comprise substantially more than three piston/cylinder units each. FIG. 10, for example, comprises a phase diagram of the operation of a seven piston/cylinder unit motor. With larger numbers of piston/cylinder units in a motor, the stress created in the teeth of the jack-up system and the time during which any single piston/cylinder unit is disengaged from the supporting legs is reduced. In addition, although FIGS. 3-8 illustrate an even number of piston/cylinder units 33 acting in pairs on the

opposing toothed racks 32 of a leg chord 26, the number of piston/cylinder units acting on the toothed racks of a single leg chord can be an odd number, so long as the number of piston/cylinder units N are phased so that N-1 piston/cylinder units are engaged with and driving the leg chords of the MODU supporting leg while one of the piston/cylinder units is being retracted for subsequent engagement. Where an odd number of piston/cylinder units is engaged with the toothed racks of a single leg chord, their positions of engagement with the toothed racks of the leg chords should be staggered, rather than opposing, as illustrated in FIGS. 3-8. While the staggered odd number of piston/cylinder units acting on toothed racks imposes shear forces acting transversely on the toothed racks and leg chord, the forces acting normal to the central axis of the leg chord and its toothed racks are not large and will impose no unacceptable shear stress on the toothed racks and leg chord.

Another feature of the invention comprises the tooth profile preferably employed in the rack engagement members 34 and the toothed racks 32. FIG. 11 illustrates, in cross section, a tooth 50 with a profile that is preferably incorporated into the teeth of the rack engagement members 34 and toothed racks 32. While the preferred tooth 50 is illustrated in FIG. 11 as one of the teeth of the toothed rack 32, the mating teeth of the toothed rack engagement members 34 will have the same mating tooth profile. In practice the toothed racks are wide, having widths, for example, of 7-10 inches, and the load bearing surfaces of the tooth 50 extend in directions perpendicular to the surface of the paper.

As indicated by FIG. 11, the tooth profile of a preferred tooth 50 includes flat and substantially vertical root and cap surfaces 51 and 52, respectively, and a pair of angled planar engagement surfaces 53 and 54, forming with respect to a substantially vertical plane 55 that includes the roots 51 of the teeth, tooth angles $\alpha 1$ for the planar upper tooth surface 53 and $\alpha 2$ for the lower planar tooth surface 54. While it is preferable that the tooth engagement surfaces 53 and 54 of tooth 50 be purely planar, manufacturing techniques, such as the use of cutting torch methods, introduce deviations from the preferred purely planar form. Further references to the "planar" surfaces of the tooth 50 include surface imperfections and variations from purely planar that do not alter the reduced stress concentration benefits of this invention. For ease of manufacture, the angles $\alpha 1$ and $\alpha 2$ are preferably equal angles, although the angle of $\alpha 2$ of the lower engagement surface 54 may be increased to decrease the disengagement forces when the supporting legs 22 and their inner racks 32 are moved upwardly with respect to the MODU platform 21. Importantly, the angle $\alpha 1$ for the upper planar engagement surfaces 53 of the toothed racks 32 is selected so that when the mating teeth of the rack engagement members 34 are being driven by the piston/cylinder units 33 in mid-stroke, the forces imposed on the upper angled planar engagement surfaces 53 of the

toothed racks 32 by the mating engaged teeth of the rack engagement members 34 is substantially perpendicular to the upper planar engagement surfaces 53 of the rack teeth 50. Because the engagement surfaces of the teeth of the rack engagement members 34 and the engagement surfaces of the teeth of the toothed racks 32 are planar, the stresses resulting from the driving forces on the engaged teeth of the rack engagement members 34 and toothed racks 32 are uniformly spread over the engaged surfaces and within the bodies of the teeth.

As well known in the art, the number of toothed racks and engaged teeth necessary to carry the maximum weight W of the MODU platform and all of its topside loads may be determined by

$$S \times T \times N \geq W$$

where S is the acceptable tensile stress of the material from which the engaged teeth will be manufactured, T is the total root area of the engaged teeth of each toothed rack and N equals the number of toothed racks. The total root area T equals the tooth pitch t (FIG. 11) of the engaged teeth times the number n of the engaged teeth (i.e., t x n). The total root area T may comprise as large an area as necessary to permit the use of readily available and inexpensive steels having modulii of elasticity, for example, on the order of 34-58 KSI, thereby eliminating the requirement for use of the special high strength steels required by the spur gear drive systems of the prior art.

In a continuous linear motion motor the geometric relationship of tooth pitch, vertical cylinder stroke, vertical distance between base mounting pins of cylinders, number of cylinders used, and cycling arrangement must meet certain geometric criteria for satisfactory operation. When configured as described below, the jacking operation will move the legs of the jack-up rig up or down in relationship to the jack-up platform and will lock the legs in position for extended periods for drilling operations or for transit.

A typical calculation to determine the geometry of a specific jack-up design follows:

Let: N = number of cylinders (or cylinder pairs) required at each leg chord to raise the jack-up platform;

V = vertical travel of the tooth (or teeth) engaged with the chord rack;

D = vertical distance between base pins of cylinders, i.e., mounting distance;

T = required tooth pitch of rack;

t = individual tooth pitches smaller than required tooth pitch may be attained by dividing "T" by 2, 3, 4, etc.;

S = cylinder stroke.

Since the cylinder may be mounted with the cylinder base pin outboard from the rod end pin, "S" will be larger than "V".

| Typical Calculation | Example |
|---|---|
| Step 1:<br>Calculate the total number of cylinders required at each leg to raise the jack-up platform, including safety factor. The number of cylinders must be evenly divisible by the number of leg chords. This result must be the next higher even number. | 54 cylinders in sets of 2 |
| Step 2:<br>Divide the number of cylinders by the number of leg chords. (9 leg chords for 3 triangular legs) | 54/9 = 6 In sets of 2 |
| Step 3:<br>Add one set of cylinders per leg chord | 6 + 1 = 7 sets of cylinders per leg chord |
| Step 4:<br>Select the desired tooth pitch "T" by calculating acceptable bearing stresses on the leg chord teeth. | 3 inch pitch |
| Step 5:<br>Multiply the tooth pitch "T" by the number of cylinders on each leg chord to find "V". | V = T*7<br>V = 3*7<br>V = 21 inches |
| Step 6:<br>Calculate "D" by subtracting maximum tooth pitch from the vertical travel of the tooth engaged with the chord rack. | D = V-T<br>D = 21-3<br>D = 18 inches |
| Step 7:<br>The piston travel S is then determined from the result and the mounting geometry. | |

FIG. 10 illustrates the correlation between the vertical cylinder stroke V and the maximum tooth pitch, or spacing T for a seven piston/cylinder unit motor.

Other possibilities exist for determining numbers of cylinders or for determining workable tooth pitch "t". Odd numbers of cylinders may be advantageous for some designs which will require the cylinders to act individually and alternately along the leg chord with the mounting of the cylinders determined in a similar manner as described in the above calculation to establish the proper geometry for cylinder position and tooth pitch.

The following table further illustrates the relationship between the number of phased piston/cylinder units and tooth spacing.

SYSTEM PHASE VS. TOOTH SPACING

| SYSTEM PHASE | 120 DEGREE | 90 DEGREE | 72 DEGREE | 60 DEGREE |
|---|---|---|---|---|
| NO. CYL. OR CYL. PAIRS - N | 3 | 4 | 5 | 6 |
| VERTICAL STROKE - V | V | V | V | V |
| MAX TOOTH SPACING - T | V/(N-1) | V/(N-1) | V/(N-1) | V/(N-1) |

For smaller teeth, the maximum tooth spacing T can be divided by a whole number, e.g., 2 or more, to obtain t.

Furthermore, as indicated above, the angled planar tooth surfaces 53 of the preferred teeth in combination with the pivotal mounting of the driving piston/cylinders 33 permit the generation, by the engaged teeth of the rack engagement members 34 and toothed racks 32, of forces that resist disengagement of the rack engagement members 34 from the toothed racks 32 when the piston/cylinder units 33 are in their retracted positions in the locking mode of operation of the system, and forces assisting disengagement of the rack engagement members 34 from the toothed racks 32 when the piston/cylinder units 33 are fully extended and ready for disengagement and repositioning during their operation in the jack-up or jack-down modes.

The cooperation of the angled planar tooth engagements surfaces 53 of the preferred teeth 50 with the pivotal attachment of the piston/cylinder units 33 is illustrated in FIGS. 12-15. FIG. 12 illustrates three piston/cylinder units 33a, 33b, and 33c with their pistons fully extended, at mid-stroke and fully retracted respectively, and FIGS. 13, 14 and 15 illustrates the force vectors at the engaged planar tooth engagement surfaces 53 of the toothed racks 32, with FIG. 13 representing the force vectors corresponding to the position of piston/cylinder units 33c, FIG. 14 representing the force vectors corresponding to the position of piston/cylinder units 33b, and FIG. 15 representing the force vectors corresponding to piston/cylinder units 33a.

As shown in FIG. 13 with the pistons of the piston/cylinder units retracted (as with piston/cylinder unit 33c of FIG. 12) and the preferred teeth 50 of the toothed rack engagement members 34 and the toothed racks 32 engaged, a closing force vector 56 is generated urging the toothed rack engagement members 34 toward the toothed racks 32 to assist in maintaining their engagement and in locking the MODU platform 21 in a stationary position with respect to the MODU supporting legs during the locking mode of the jacking system.

As shown in FIG. 14, when the piston/cylinder units are in mid-stroke (as with the piston/cylinder unit 33b of FIG. 12), the force vector 57 resulting from the pistons of the piston/cylinder units is perpendicular to the planar engagement surfaces 53 of the toothed racks 32.

As shown in FIG. 15 with the pistons of the piston/cylinder units fully extended (as with the piston/cylinder unit 33a of FIG. 12) an opening force vector 58 is generated urging the toothed rack engagement members 34 away from the toothed racks 32. The opening force 58 must be resisted by the compression springs of the preferred engagement/disengagement means 35 but will assist in the disengagement of the toothed rack engagement members 34 prior to their retraction and re-engagement.

As the MODU platform 21 is lowered in the jack-down mode at a rate controlled by the plurality of piston/cylinder units 33, the upward forces generated by the resistance of the pistons in controlling the lowering of the MODU platform 21 will generate, by the engagement of the lower angled toothed surfaces 54 of the toothed racks 32 with the corresponding mated surfaces of the rack engagement members 34, an opening force (like force 58) acting to disengage the rack engagement members 34 from the toothed racks 32, and such forces must be overcome by the forces exerted by the compression springs of the engagement/disengagement means 35 that maintain the rack engagement members 34 in engagement with the toothed racks 32. These opening forces acting to disengage the rack engagement members 34 from the toothed racks 32 as the MODU is lowered can be reduced by increasing the tooth angle $\alpha 2$ of the lower planar engagement surfaces to be, for example, more substantially normal to the vertical plane 55.

The hydraulic system will, preferably, use a pressure compensated variable volume hydraulic pump or pumps for generation of the hydraulic pressure, enabling the speed of movement of the pistons to be controlled. In addition, over center valves may be used to require the presence of positive hydraulic pressure at the cylinders before the pistons are moved in the jack down mode. The jacking system will, as apparent to those skilled in the art, also include the controllable hydraulic valves necessary to control the sequenced application of hydraulic fluid and pressure to the piston/cylinder units 33 and the unclamping piston/cylinder units of the preferred engagement/disengagement means 35, accumulators, if needed, to accelerate the operation of the pistons of the piston/cylinder units 33, and direction flow valves, relief valves, load cells and motion sensors, as needed.

As noted above, the piston/cylinder units of the continuous linear motion motors for each supporting leg can be connected to a common hydraulic fluid supply line so that the same hydraulic pressure is exerted on all the piston/cylinder units acting on that leg. Thus,

any resistance to movement of one leg chord of a supporting leg will increase the pressure and forces acting on all of the leg chords of the supporting leg and tend to maintain uniform motion of all of the leg chords.

The invention thus provides a new jack-up MODU and MODU jacking system that can reliably handle loads several times greater than can be currently handled, can be readily and inexpensively designed and scaled for different jack-up loads, and can save millions of dollars in the manufacture of a single jack-up MODU.

The jacking system of the invention provides, as indicated above, jack-up, jack-down and locking modes of operations and permits monitoring and control of leg loads and the rates of relative movement. Operation of the jacking system, in the invention, is preferably controlled by a programmable logic computer, which can control operation of one or a plurality of sources of hydraulic pressure, operation of each of the continuous linear motion motors driving each of the toothed racks of each of the supporting legs by sequencing the operations of valves controlling the flow of hydraulic fluid and the application of hydraulic pressure to the piston/cylinder units of the motors, and by controlling the rates of relative motion. The computer control can also sequence operation of the valves and piston/cylinder units to position the pistons and toothed rack engagement members of the continuous linear motion motors for providing motion, in changing from the locking mode to the jack-up or jack-down modes, and can cease motion of the pistons of the piston/cylinder units of the continuous linear motion motors and sequentially retract their pistons and engage their rack engagement members in changing from the jack-up or jack-down modes to the locking mode.

In addition, the computer control can also monitor the output signals of load cells 38 located in the pivot attachments 33p of the plurality of piston/cylinder units 33, as shown in FIG. 3B, for sensing the loads on each of the leg chords of each of the supporting legs and/or outputs of motion sensors 39 for sensing the rate of movement of each of the leg chords of each of the supporting legs, as shown in FIG. 3A, and can provide quantitative read-outs thereof and warnings of unacceptable operating conditions.

FIG. 16 illustrates one possible screen presentation 60 of such a computer control, which provides touch screen selection of the modes of operation of each supporting leg, quantitative presentations of the jacking speed, the hydraulic pressure acting on each supporting leg and the load imposed on each supporting leg. In such a screen presentation, the representations of the legs can change color or flash with or without an audible noise, to warn of an unacceptable operating condition.

The description and illustrations of the invention presented here are of specific preferred embodiments and simplified examples. As will be apparent to those skilled in the

art, the invention is not limited to the specific embodiments described and illustrated, but is defined in its scope by the following claims.